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Sustained increases in blood pressure elicited by prolonged face cooling in humans

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Abstract

We tested the hypothesis that increases in blood pressure are sustained throughout 15 min of face cooling. Two independent trials were carried out. In the Face Cooling Trial, ten healthy adults underwent 15 min of face cooling where a 2.5 L bag of ice water (0 ± 0°C) was placed over their cheeks, eyes, and forehead. The Sham Trial was identical except that the temperature of the water was 34 ± 1°C. Primary dependent variables were forehead temperature, mean arterial pressure, and forearm vascular resistance. The square root of the mean of successive differences in R-R interval (RMSSD) provided an index of cardiac parasympathetic activity. In the Face Cooling Trial, forehead temperature fell from 34.1 ± 0.9°C at baseline to 12.9 ± 3.3°C at the end of face cooling ($P<0.01$). Mean arterial pressure increased from 83 ± 9 mmHg at baseline to 106 ± 13 mmHg at the end of face cooling ($P<0.01$). RMSSD increased from 61 ± 40 ms at baseline to 165 ± 97 ms during the first two min of face cooling ($P\leq0.05$), but returned to baseline levels thereafter (65 ± 49 ms, $P\geq0.46$). Forearm vascular resistance increased from 18.3 ± 4.4 mmHg/ml/100 g tissue/min at baseline to 26.6 ± 4.0 mmHg/ml/100 g tissue/min at the end of face cooling ($P<0.01$). There were no changes in the Sham Trial. These data indicated that increases in blood pressure are sustained throughout 15 min of face cooling and face cooling elicits differential time-dependent parasympathetic and likely sympathetic activation.

Keywords: Parasympathetic activation, sympathetic activation, diving reflex, trigeminal nerve

Introduction

Apnea and immersion of the face in cold water evokes the 'diving reflex', which plays an important oxygen-conserving role in diving mammals and birds (4). Cooling of the forehead and cheeks evokes a similar, yet less pronounced, response in humans (1, 3, 7, 11, 14, 15, 18, 19, 21, 22), which occurs secondary to stimulation of the cold afferents of the trigeminal nerve (10, 17). Face cooling in humans simultaneously stimulates the parasympathetic and sympathetic nervous systems, evoking bradycardia and peripheral vasoconstriction (1, 3, 7, 11, 14, 15, 18, 19, 21, 22). In humans, reductions in heart rate are not sufficient to reduce cardiac output (3). Therefore, blood pressure increases as a result of systemic peripheral vasoconstriction (1, 3, 7, 11, 14, 15, 18, 19, 21, 22).

The hemodynamic responses to face cooling in humans have only been studied up to 180 s in duration (1, 3, 7, 11, 14, 15, 18, 19, 21, 22). Thus, it is unknown if the relative hypertensive responses elicited by face cooling, in addition to the temporal dynamics of parasympathetic and sympathetic activation, are sustained beyond 180 s. The diving reflex in diving mammals and birds persists for the duration of the dive (4). Therefore, as long as the cooling stimulus is present it is likely that the hemodynamic responses to face cooling are also sustained in humans. We tested the hypothesis that increases in blood pressure are sustained throughout 15 min of face cooling. The testing of this hypothesis, in addition to understanding the magnitude and time course of parasympathetic and sympathetic activation, will provide important insights regarding the potential utility of face cooling as a simple and effective intervention for restoring or stabilizing blood pressure in individuals suffering from orthostatic hypotension (9) or those who have incurred an injury or illness rendering them acutely hypotensive (e.g., traumatic hemorrhage (12), Dengue fever (13) or sepsis (23)).

Methods

Two separate studies were undertaken to test the hypothesis. The first study was the Face Cooling Trial, which examined the effects of 15 min of face cooling on blood pressure. The second study was a Sham Trial. This trial was deemed necessary to examine if the pressure exerted by the face cooling modality independently contributed to the pressor response observed during the Face Cooling Trial. The Sham Trial was added post hoc and thus, the data from the Face Cooling Trial were collected before that of the Sham Trial. Furthermore, a different cohort of subjects completed the Face Cooling and Sham Trials.

Subjects

A power analysis performed from data obtained during pilot testing (α=0.05, effect size (f)=1.2) indicated that at least two subjects were required to achieve power >0.8 to observe statistically significant increases in mean arterial pressure during face cooling (8). Thus, ten healthy young subjects were recruited to participate in each study. The subject characteristics for the two studies were - Face Cooling Trial: age: 22 ± 2 y, height: 174 ± 10 cm, weight: 73.0 ± 12.9 kg, 3 females; Sham Trial: age: 25 ± 4 y, height: 172 ± 13 cm, weight: 72.2 ± 17.6 kg, 6 females. All subjects were physically active, non-smokers, not taking medications, and reported to be free from any known cardiovascular, metabolic, neurological, or psychological diseases. Female subjects were not pregnant, which was confirmed via a urine pregnancy test. Menstrual cycle phase and time of day were not controlled. Each subject was fully informed of the experimental procedures and possible risks before giving informed, written consent. The study was approved by the Institutional Review Board at the University at Buffalo, and performed in accordance with the standards set by the latest revision of the Declaration of Helsinki. For both the Face Cooling and Sham Trials, subjects visited the laboratory on two occasions. Visit one was a screening and familiarization visit and visit two was the experimental trial.

Instrumentation and measurements

Height and weight were measured with a stadiometer and scale (Sartorius Corp. Bohemia, NY, USA). Heart rate was measured continually from a 3 lead ECG (DA100C, Biopac Systems, Inc. Goleta, CA, USA). Beat-to-beat blood pressure was measured via the Penaz method (Finometer Pro, FMS, Amsterdam, The Netherlands). These data were confirmed intermittently via auscultation of the brachial artery by electrosphygmomanometry (Tango M2,

SunTech Raleigh, NC, USA), and no corrections were necessary. Stroke volume was estimated from the blood pressure waveform using Modelflow (25). Skin blood flow was measured via integrated laser Doppler flowmetry (Periflux System 5010, Perimed, Stockholm, Sweden) on the dorsal surface of the left forearm. The local temperature of this location was clamped at 34°C using a local heating device (Periflux System 5020, Perimed, Stockholm, Sweden), ensuring any changes in cutaneous vasomotor tone were reflex mediated. Forearm blood flow was measured on the right arm via venous occlusion plethysmography (27). This was accomplished by placing a strain gauge (D.E. Hokanson, Inc., Bellevue, WA, USA) around the widest circumference of the forearm and pressure cuffs on the wrist and upper arm proximal to the elbow. During each measurement period, the wrist cuff was inflated to 250 mmHg, while the cuff on the upper arm cycled between 0 mmHg and 50 mmHg every 8 s, thereby temporarily occluding venous return. Forearm blood flow during each cycle was determined from the slope of the increase in forearm volume determined from the strain gauge and is presented as the average of six consecutive measurements at each measurement time period (28). Forehead skin temperature was measured with a thermocouple (Omega Engineering, Inc. Stamford, CT, USA) adhered to the forehead with permeable tape (Transpore, 3M, St. Paul, MN, USA).

Experimental protocol

Subjects arrived at the laboratory having refrained from strenuous exercise, alcohol and caffeine for 12 h, and food for 2 h. Following instrumentation, subjects assumed the supine position in a temperature controlled laboratory (24 ± 1°C, 35 ± 15% relative humidity). Following at least 10 min rest, baseline measurements were taken over the next 10 min. At the end of this period, the 15 min face cooling or sham period commenced. Face cooling was achieved by placing a flexible bag of ice water directly on the forehead, eyes, and cheeks, as cooling these areas most strongly elicits the diving reflex in humans (20). During the Sham Trial, the bag contained thermoneutral water. In both the Face Cooling and Sham Trials the volume of the water was 2.5 L and the bag was agitated every 3 min. The temperature of the water was measured with a thermocouple (Omega Engineering, Inc. Stamford, CT, USA) immediately before application and after the 15 min face cooling or sham period. During the Face Cooling Trial, pre- and post- application water temperatures were not different (pre-: 0 ± 0°C, post-: 0 ± 1°C, $P=0.79$), while the Sham Trial water temperature decreased slightly with application (pre-: 34 ± 1°C, post-: 33 ± 1°C, $P<0.01$). During the face cooling and sham

periods, respiratory rate and tidal volume were not controlled, but subjects were encouraged to breath normally. Following the face cooling and sham periods, subjects remained in the supine position for another 5 min allowing the collection of recovery data.

Data and statistical analyses

All data were sampled continuously at 1 kHz via a data acquisition system (Biopac MP150, Goleta, CA, USA). Except for forearm blood flow (see below), data were analyzed at 5 and 10 min of baseline, at 1, 2, 3, 6, 9, 12 and 15 min of face cooling, and at the end of recovery (all 60 s averages). Data were analyzed each minute during the first three minutes of face cooling or the sham period to compare our findings to those of other laboratories that used a shorter face cooling procedure. During each analysis time period, R-R intervals were calculated from the ECG. An estimate of short term changes in cardiac parasympathetic activity was derived from the square root of the mean of successive differences in R-R interval (RMSSD) (5), using WinCPRS software (Absolute Aliens, Turku, Finland). Forearm blood flow was measured at 5 and 10 min of baseline, at 3, 9 and 15 min of face cooling, and at the end of recovery (all the average of 6 consecutive measurements). Cutaneous and forearm vascular resistances were calculated as the quotient of mean arterial pressure and the measured blood flow at each time point. Cardiac output was calculated as the product of stroke volume and heart rate, while total peripheral resistance was calculated as the quotient of mean arterial pressure and cardiac output.

Data during each Trial were analyzed using one-way repeated measures ANOVA. Given the post hoc nature of the Sham Trial, no direct comparisons were made between the two trials. In all instances, data were assessed for approximation to a normal distribution and sphericity, and no corrections were necessary. When the ANOVA revealed a significant F value, post hoc Dunnett's test pairwise comparisons were made. This test compared all values to those obtained at the 10 min Baseline time point. This analysis was determined a priori and was deemed ideal to test our hypothesis. Data were analyzed using Prism software (Version 6, GraphPad Software Inc. La Jolla, CA, USA). A priori statistical significance was set at $P \leq 0.05$ and actual P-values are reported where possible. Data are reported as mean ± SD.

Results

Face Cooling Trial

Forehead skin temperature fell from 34.1 ± 0.9°C at baseline to 12.9 ± 3.3°C at the end of face cooling (P<0.01), and began to return to baseline during recovery (28.4 ± 2.7°C), but it was still lower than baseline (P<0.01, Figure 1).

Blood pressure response

Mean arterial pressure increased from 83 ± 9 mmHg at baseline to 106 ± 13 mmHg at the end of face cooling (P<0.01) and was also higher than baseline during recovery (96 ± 9 mmHg, P<0.01, Figure 2). Systolic (baseline: 116 ± 11 mmHg, after 15 min face cooling: 139 ± 16 mmHg, recovery: 127 ± 13 mmHg, P≤0.03) and diastolic (baseline: 64 ± 7 mmHg, after 15 min face cooling: 79 ± 11 mmHg, recovery: 71 ± 8 mmHg, P≤0.01) blood pressure followed a similar trajectory to that observed for mean arterial pressure.

Cardiac response

Cardiac output (P=0.21, Figure 2), heart rate (P=0.16, Figure 3), and R-R interval (P=0.16, Figure 3) did not change from baseline throughout face cooling or during recovery. Stroke volume also did not change throughout (baseline: 97 ± 18 mL, after 15 min face cooling: 107 ± 23 mL, recovery: 102 ± 21 mL, P=0.30). However, RMSSD was elevated during the first 2 min of face cooling (P<0.05), which returned to baseline levels thereafter (P≥0.46, Figure 3).

Vascular resistance response

Total peripheral resistance rose from 14.8 ± 4 mmHg/L/min at baseline to 21.2 ± 7.9 mmHg/L/min after 2 min of face cooling (P=0.02, Figure 2). Cutaneous vascular resistance followed a similar trajectory, while forearm vascular resistance was higher than baseline after 9 min of face cooling (P≤0.04, Figure 4). Absolute skin blood flow did not change from baseline, throughout face cooling or during recovery (baseline: 40 ± 20 PU, after 15 min face cooling: 33 ± 16 PU, recovery: 33 ± 15 PU, P=0.26). Similarly, absolute forearm blood flow did not change from baseline, throughout face cooling or during recovery (baseline: 4.8 ± 1.3 mL/100 g tissue/min, after 15 min face cooling: 4.1 ± 0.8 mL/100 g tissue/min, recovery: 4.9 ± 1.3 mL/100 g tissue/min, P=0.25).

Sham Trial

Forehead skin temperature rose slightly during the initial stages of the sham period (P≤0.04), but was not different from baseline thereafter (Table 1).

Blood pressure response

Mean arterial pressure did not change throughout (P=0.56, Table 1), and neither did systolic (baseline: 114 ± 8 mmHg, after 15 min sham period: 112 ± 11 mmHg, recovery: 113 ± 11 mmHg, P=0.61) or diastolic (baseline: 62 ± 4 mmHg, after 15 min sham period: 60 ± 6 mmHg, recovery: 62 ± 7 mmHg, P=0.48) pressures.

Cardiac response

Cardiac output (P=0.46), heart rate (P=0.41), R-R interval (P=0.45) and RMSSD (P=0.08) did not change throughout the sham period or recovery (Table 1). Stroke volume also did not change (baseline: 91 ± 9 mL, after 15 min sham period: 92 ± 20 mL, recovery: 86 ± 12 mL, P=0.30).

Vascular resistance response

Total peripheral resistance (P=0.38), cutaneous vascular resistance (P=0.67), and forearm vascular resistance (P=0.14) did not change from baseline throughout the sham period or during recovery (Table 1). Absolute skin blood flow did not change from baseline, throughout the sham period or during recovery (baseline: 24 ± 10 PU, after 15 min sham period: 22 ± 10 PU, recovery: 22 ± 10 PU, P=0.37). Absolute forearm blood flow decreased slightly from baseline (4.5 ± 2.1 mL/100 g tissue/min) to the end of the 15 min sham period (3.8 ± 1.4 mL/100 g tissue/min, P=0.05), but was not different from baseline during recovery (3.9 ± 1.5 mL/100 g tissue/min, P=0.30).

Discussion

In support of our hypothesis, increases in mean arterial pressure were sustained throughout 15 min of face cooling (Figure 2). This was driven by increases in both systolic and diastolic pressure. Despite no changes in heart rate (Figure 3), stroke volume, or cardiac output (Figure 2), prolonged face cooling revealed an increase in parasympathetic activation (i.e., RMSSD) that abated by the third minute (Figure 3). Given that cardiac output did not change, the sustained increase in blood pressure with face cooling was likely a function of sympathetically mediated elevations in vascular resistance. In the present study this was evident in initial increases in total peripheral (Figure 2) and cutaneous vascular resistances (Figure 3) and more sustained increases in forearm vascular resistance (Figure 3) during face cooling. Given that blood pressure and associated hemodynamic parameters did not change during the sham period (Table 1), the observed effects of face cooling on blood pressure occur largely independent of the pressure exerted by our face cooling modality, and thus are likely a function of temperature sensitive afferent activation. Collectively, our findings suggest that 15 min of face cooling in young healthy adults elicits: i) a transient increase in parasympathetic activity, which does not affect cardiac output, and ii) sustained increases in vascular resistance that promote increases in blood pressure, which are sustained as long as the cooling stimulus remains in place.

Face cooling elicits sustained increases in blood pressure

It is well established that face cooling elicits a pressor response in humans for up to 180 s (1, 3, 7, 11, 14, 15, 18, 19, 21, 22). The present study extends these findings and has identified that face cooling induced increases in blood pressure can be sustained for at least 15 min (Figure 2). Together with findings from diving mammals and birds (4), these findings suggest that as long as the cooling stimulus remains present the hypertensive response to face cooling persists.

The mechanisms underlying face cooling induced increases in blood pressure likely stem from the activation of the sympathetic nervous system. It is well known that face cooling elicits robust increases in sympathetic nerve activity (11, 15, 21) and thus, vascular resistance in the peripheral (11, 16), visceral (6, 19), and cerebral (3) vasculatures. Ultimately, these responses elevate blood pressure (1, 3, 7, 11, 14, 15, 18, 19, 21, 22), as cardiac output remains largely unaffected by face cooling in humans (Figure 2). The present study supports and extends these findings, such that the increases in vascular resistance were evident both in the early

(total peripheral and cutaneous vascular resistances) and later (forearm vascular resistance) stages of the 15 min of face cooling. Furthermore, the increase in blood pressure was evident throughout face cooling (Figure 2). Although we do not have a direct measure of sympathetic activation (i.e., muscle sympathetic nerve activity), the present study provides indirect evidence for sympathetic activation that persists throughout 15 min of face cooling.

Our prolonged face cooling paradigm permitted us to gain unique insights regarding the transient nature of parasympathetic activation associated with stimulating the trigeminal nerve. It is well established that face cooling activates the parasympathetic nervous system (1, 3, 11, 14, 18, 22). Previous studies have limited the duration of observation to 180 s or less (1, 3, 11, 14, 18, 22). Thus, these previous studies were unable to detect the transient nature of parasympathetic activation during face cooling. This was demonstrated in the present study by a sharp rise in RMSSD during the first and second minutes of face cooling that returned to baseline after 3 min (Figure 3). Thus, face cooling elicits acute and dynamic parasympathetic activation in humans that returns to baseline levels despite that the cooling stimulus remains present. The reason heart rate did not significantly change during the initial stages of face cooling, despite parasympathetic activation, is not clear from the present study. Notably however, this is not an uncommon observation (11, 19, 21). It has been speculated that during instances of relatively high basal parasympathetic activity, as would occur in resting healthy young adults (26), that additional parasympathetic activation would not elicit further decreases in heart rate (i.e., a basement effect) (11, 19). We agree with this contention, but direct evidence is warranted.

Considerations

A few methodological considerations warrant mentioning. First, we did not specifically control respiratory rate and/or tidal volume, which may have impacted our RMSSD analysis (5). That said, we believe that any influence of nominal respiratory instability on our index of cardiac parasympathetic activation was minimal based on data indicating there are no changes in respiratory rate (21) or end tidal carbon dioxide tension (3) throughout face cooling. However, it remains unknown if prolonged face cooling alters respiration. Second, given the benefits of beat-to-beat monitoring, we used Modelflow to estimate stroke volume (2). However, the estimation of stroke volume via Modelflow assumes that aortic impedance remains constant (25). Notably, it is unknown if aortic impedance changes during face cooling. Finally, we tested both males and females and we did not control for menstrual cycle phase in

our female subjects. This was by design because this study aimed to provide the foundation for face cooling as a therapy for hypotensive states. Notably, we are underpowered to conduct a formal analysis between males and females. Furthermore, menstrual cycle hormones modulate the mechanisms underlying blood pressure regulation (24). Thus, the hemodynamic responses, and the underlying mechanisms, elicited by face cooling might be modulated by menstrual cycle phase.

Perspectives

The present study provides insights regarding the potential utility of face cooling as a simple intervention for restoring and/or stabilizing blood pressure in individuals suffering from orthostatic hypotension (9) or those who have incurred an injury or illness rendering them hypotensive (e.g., traumatic hemorrhage (12), Dengue fever (13) or sepsis (23)). That said, a number of unknowns preclude the translation of face cooling to clinical practice. For instance, it currently remains unknown if the cardiac parasympathetic activation elicited by face cooling is capable of compromising cardiac output in the presence of hypotension. It could be argued that baroreflex initiated cardiac sympathetic activation could buffer face cooling induced parasympathetic activation, preventing a reduction in cardiac output. Alternatively, cardiac parasympathetic activation is greatly reduced during hypotension. Therefore, any activation of the parasympathetic nervous system may have a greater effect on heart rate than that observed in the present study, which was conducted in the normotensive state. Furthermore, it currently remains unknown if sympathetically induced increases in vascular resistance would occur with face cooling in the presence of baroreflex induced sympathetic vasoconstriction, as would occur during hypotension. Collectively, such circumstances could limit the capacity by which blood pressure could be increased by face cooling. Clearly, further research is warranted to understand interactions between cardiac- and vascular- baroreflex activation and prolonged face cooling on blood pressure control.

Conclusions

We have demonstrated that increases in blood pressure are sustained throughout 15 min of face cooling. This effect is likely mediated primarily via activation of thermal, not pressure, sensitive afferents. Furthermore, prolonged face cooling elicited dynamic parasympathetic and sympathetic activation. Cardiac parasympathetic activation increased during the first 2 min of face cooling and returned to baseline levels thereafter, while increases in vascular resistance,

which were likely sympathetically mediated, were evident throughout the 15 min of face cooling. These findings suggest that face cooling elicits robust increases in blood pressure that are sustained as long as the cooling stimulus remains in place.

Acknowledgements and Disclosures

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Table

Table 1: Blood pressure, cardiac, and vascular resistance responses during the Sham Trial.

Stage	Baseline		Sham Period							Recovery
Time (min)	5	10	1	2	3	6	9	12	15	5
Forehead skin temperature (°C)	33.3 ± 0.8	33.3 ± 0.8	34.0 ± 0.6 [B]	34.2 ± 0.7 [B]	34.2 ± 0.7	34.0 ± 0.8	33.8± 0.8	33.8± 0.8	33.7 ± 0.8	33.4 ± 0.7
Blood pressure response										
Mean arterial pressure (mmHg)	81 ± 5	82 ± 5	80 ± 6	81 ± 6	80 ± 6	81 ± 6	81 ± 10	81 ± 8	81 ± 8	83 ± 10
Cardiac response										
Cardiac output (L/min)	5.5 ± 1.2	5.5 ± 1.3	5.5 ± 1.0	5.2 ± 1.1	5.2 ± 1.1	5.2 ± 1.1	5.5 ± 1.5	5.4 ± 1.4	5.6 ± 1.4	5.2 ± 1.0
Heart rate (bpm)	59 ± 11	59 ± 12	59 ±10	58 ± 11	58 ± 10	57 ± 10	61 ± 12	59 ± 10	60 ± 9	60 ± 11
R-R interval (ms)	1058 ± 194	1042 ± 191	1037 ± 162	1058 ± 169	1058 ± 176	1071 ± 174	1010 ± 207	1047 ± 161	1042 ± 165	1031 ± 171
RMSSD (ms)	58 ± 36	59 ± 31	56 ± 29	57 ± 31	59 ± 31	64 ± 34	64 ± 30	72 ± 40	68 ± 35	58 ± 29
Vascular resistance response										
Total peripheral resistance (mmHg/L/min)	15.4 ± 2.9	15.6 ± 3.0	14.9 ± 2.7	15.9 ± 3.0	15.7 ± 2.9	16.0 ± 2.9	15.3 ± 3.2	15.6 ± 3.3	15.3 ± 3.6	16.3 ± 3.0
Cutaneous vascular resistance (mmHg/PU)	4.7 ± 3.8	4.8 ± 4.4	4.8 ± 3.9	4.7 ± 4.3	5.3 ± 6.0	4.9 ± 4.4	4.8 ± 3.4	5.0 ± 3.9	5.1 ± 4.4	5.1 ± 3.9
Forearm vascular resistance (mmHg/mL/100 g tissue/min)	20.2 ± 7.8	21.4 ± 8.3	--	--	22.8 ± 8.2	--	23.4 ± 8.7	--	23.1 ± 6.9	23.1 ± 7.6

Mean ± SD, RMSSD: root mean square of successive differences of the R-R interval, [B] different from 10 min Baseline time point ($P \leq 0.04$).

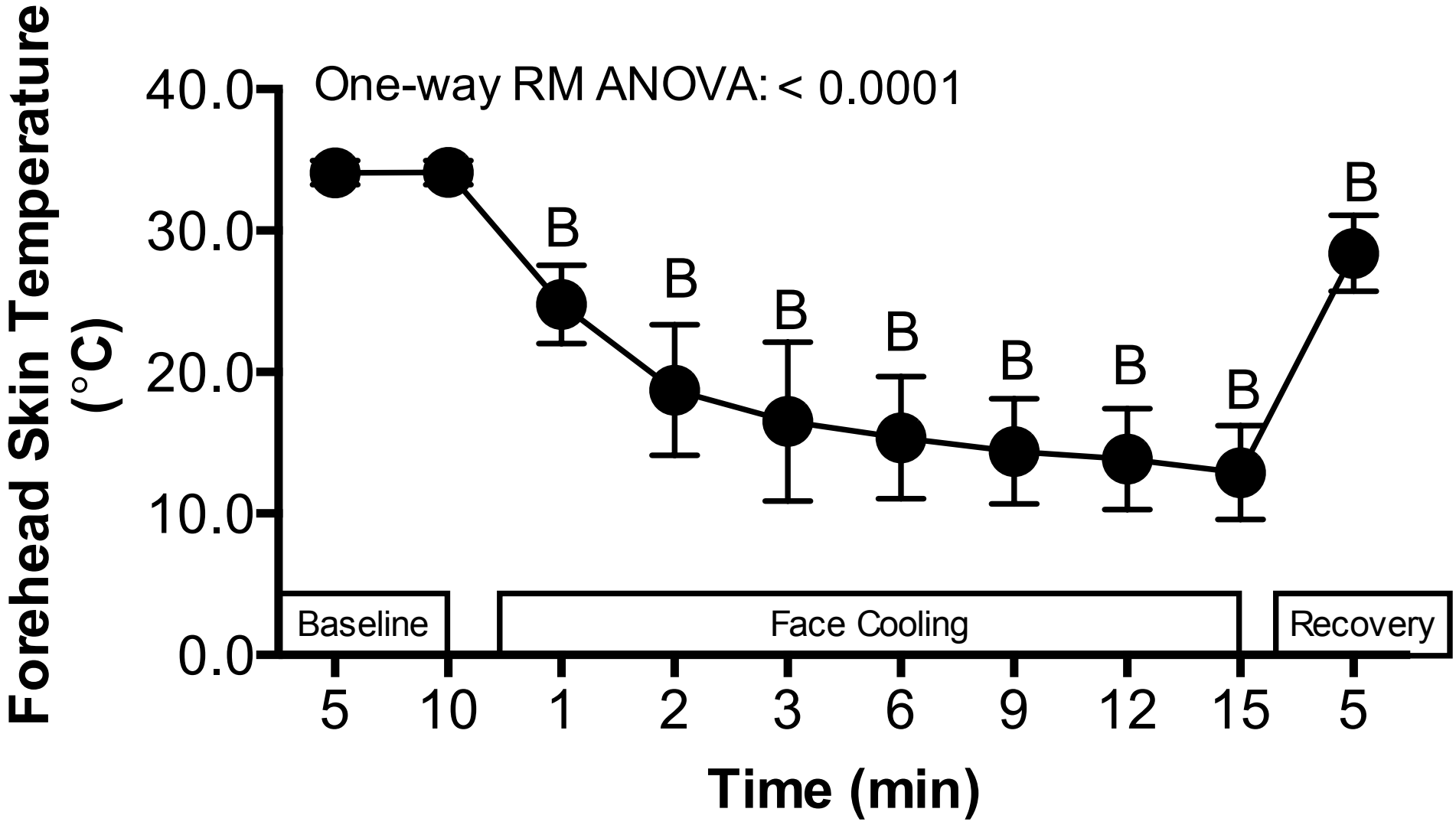
Figure Legends

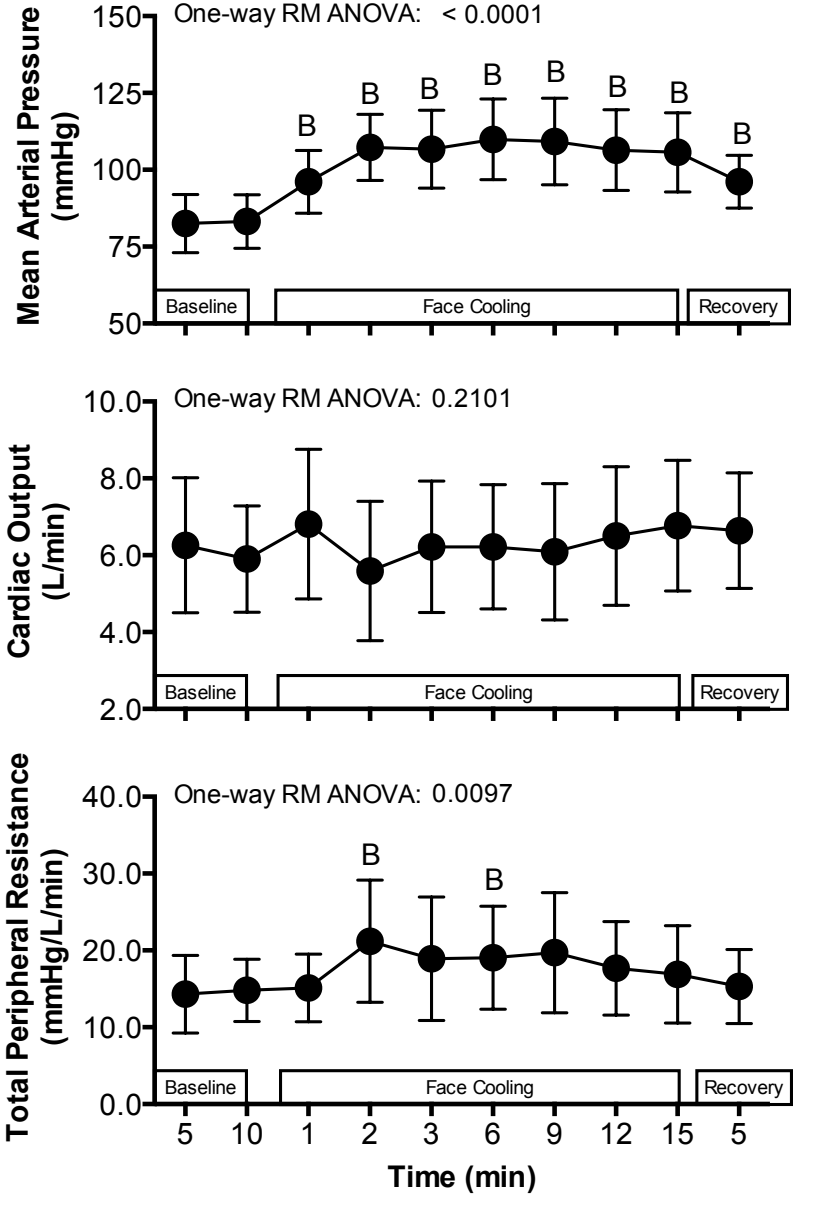
Figure 1: Forehead skin temperature at baseline, during face cooling, and during recovery in the Face Cooling Trial. Mean ± SD, n=10. [B] different from 10 min Baseline time point (P<0.01). P-value for one-way repeated measures (RM) ANOVA is noted.

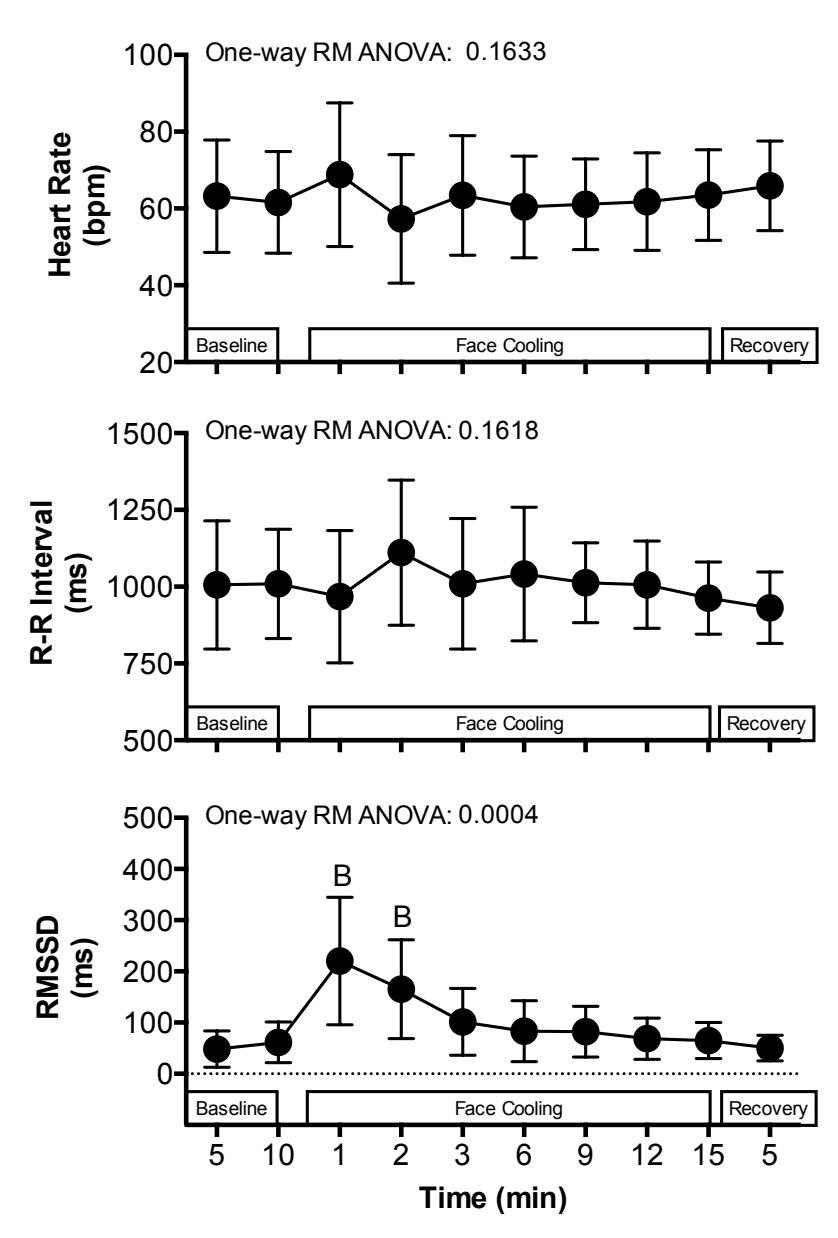
Figure 2: Mean arterial pressure (top), cardiac output (middle) and total peripheral resistance (bottom) at baseline, during face cooling, and during recovery in the Face Cooling Trial. Mean ± SD, n=10. [B] different from 10 min Baseline time point (P≤0.05). P-values for one-way repeated measures (RM) ANOVAs are noted.

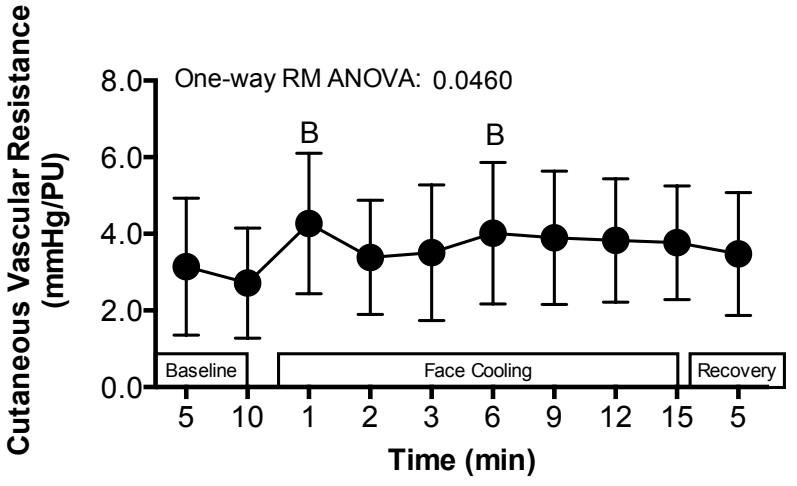
Figure 3: Heart rate (top), R-R Interval (middle) and the root mean square of successive differences of the R-R interval (RMSSD, bottom) at baseline, during face cooling, and during recovery in the Face Cooling Trial. Mean ± SD, n=10. [B] different from 10 min Baseline time point (P≤0.05). P-values for one-way repeated measures (RM) ANOVAs are noted.

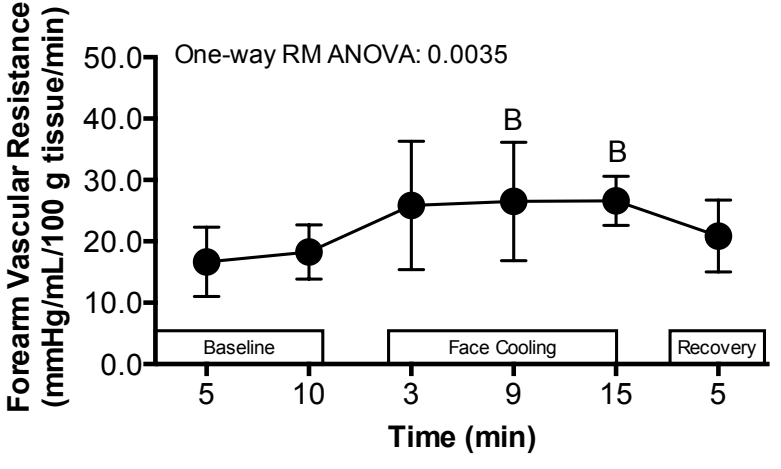
Figure 4: Cutaneous vascular resistance (top) and forearm vascular resistance (bottom) at baseline, during face cooling, and during recovery in the Face Cooling Trial. Mean ± SD, n=10. [B] different from 10 min Baseline time point (P≤0.04). P-values for one-way repeated measures (RM) ANOVAs are noted.


Forehead Skin Temperature (°C)
40.0
30.0
20.0
10.0
0.0
One-way RM ANOVA: < 0.0001
B
B
B
B
B
B
B
Baseline
Face Cooling
Recovery
5
10
1
2
3
6
9
12
15
5
Time (min)


Mean Arterial Pressure (mmHg)
One-way RM ANOVA: < 0.0001
150
125
100
75
50
B
B
B
B
B
B
B
Baseline
Face Cooling
Recovery
Cardiac Output (L/min)
One-way RM ANOVA: 0.2101
10.0
8.0
6.0
4.0
2.0
Baseline
Face Cooling
Recovery
Total Peripheral Resistance (mmHg/L/min)
One-way RM ANOVA: 0.0097
40.0
30.0
20.0
10.0
0.0
B
B
Baseline
Face Cooling
Recovery
5
10
1
2
3
6
9
12
15
5
Time (min)


Heart Rate (bpm)
One-way RM ANOVA: 0.1633
100
80
60
40
20
Baseline
Face Cooling
Recovery
R-R Interval (ms)
One-way RM ANOVA: 0.1618
1500
1250
1000
750
500
Baseline
Face Cooling
Recovery
RMSSD (ms)
One-way RM ANOVA: 0.0004
500
400
300
200
100
0
B
B
Baseline
Face Cooling
Recovery
5
10
1
2
3
6
9
12
15
5
Time (min)


Cutaneous Vascular Resistance (mmHg/PU)
One-way RM ANOVA: 0.0460
8.0
6.0
4.0
2.0
0.0
B
B
Baseline
Face Cooling
Recovery
5
10
1
2
3
6
9
12
15
5
Time (min)


Forearm Vascular Resistance (mmHg/mL/100 g tissue/min)
One-way RM ANOVA: 0.0035
50.0
40.0
30.0
20.0
10.0
0.0
B
B
Baseline
Face Cooling
Recovery
5
10
3
9
15
5
Time (min)